



Selection of an optimal set of sources to define a stable CRF

***An update on previous studies from
Martine Feissel-Vernier
using ICRF2 sources***

**Karine Le Bail
NVI Inc at GSFC/NASA, Greenbelt, MD**



Agenda

- ICRF;
- Criteria for stability:
 - MFV;
 - KLB.
- Effect of source stability on ICRF;
- Conclusions and perspectives.

ICRF-2 - Sources map

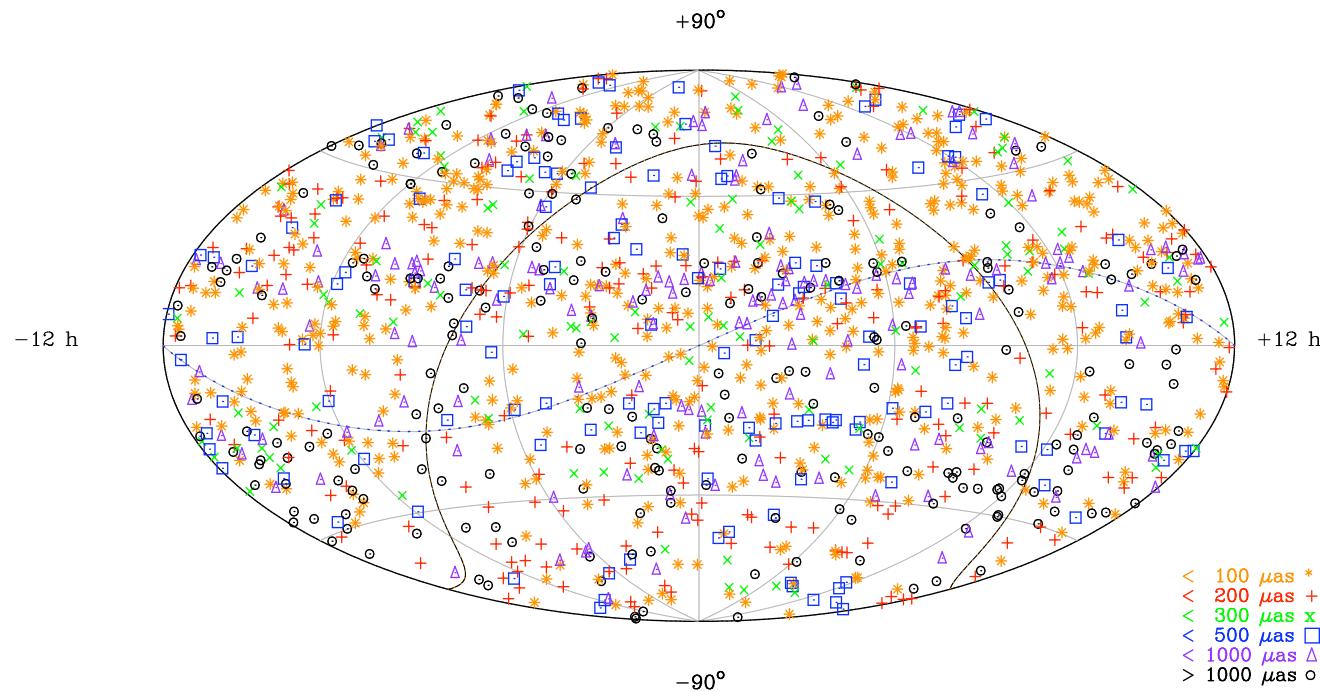


Fig. 42.— gsf008a distribution of 1448 multi-session sources (at least 2 observing sessions). The un-inflated $1-\sigma$ formal declination errors are color coded according to the legend in the figure. The median $\sigma_\delta = 175 \mu\text{as}$. The center is $(\alpha, \delta) = (0, 0)$. The Galactic plane is the roughly Ω -shaped line surrounding the center. The ecliptic plane is the dashed line. The single-session survey sources used to densify are shown in the next figure, Figure 43.



What is a good source to define a stable ICRF?

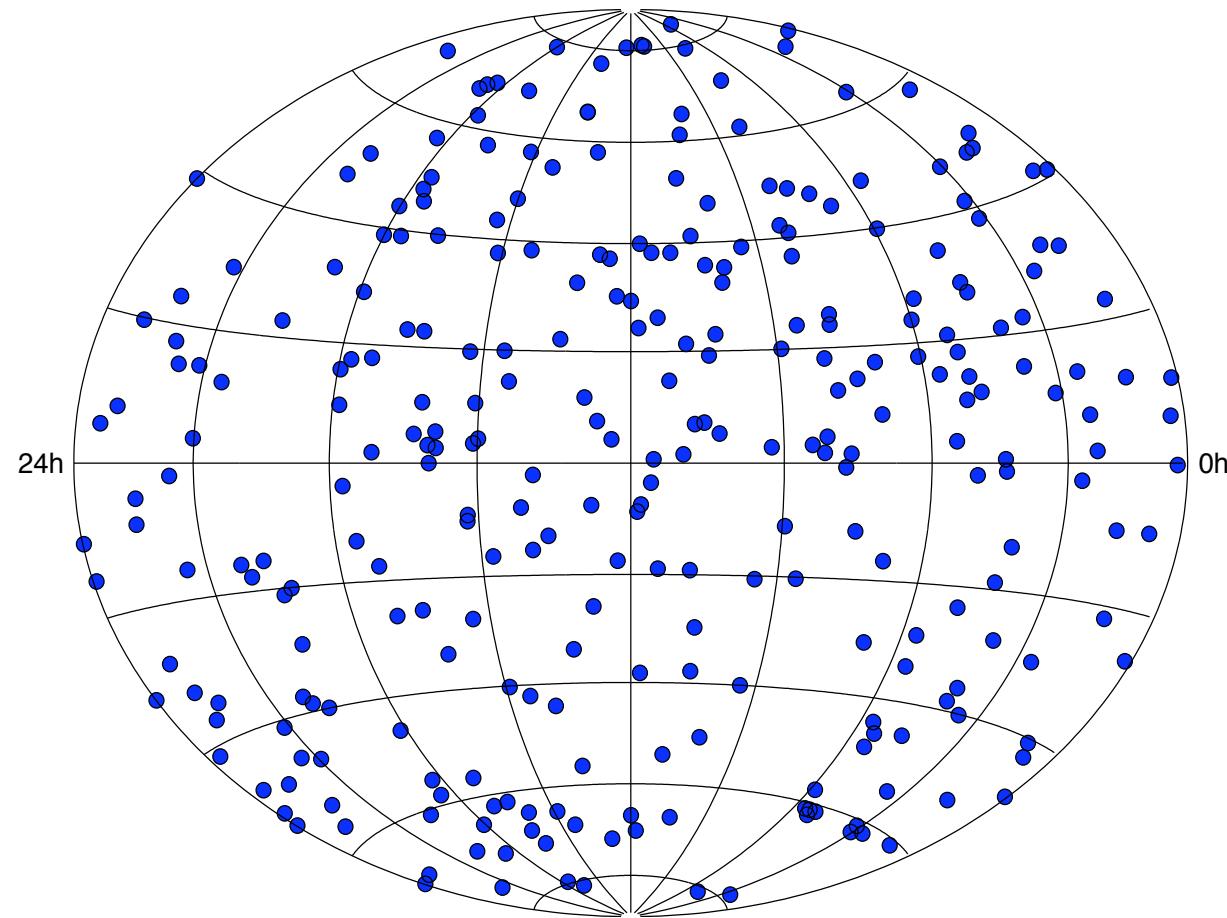


What is a good source to define a stable ICRF?

- Network (even distribution over of the sky);
- Observation (strength, compact mass);
- Quality of the observations (time span, standard deviation);
- Long-term quality:
 - Structure (drift, tendency, periodic signals);
 - Level and type of noise of the source time series.



ICRF-2 : 295 defining sources





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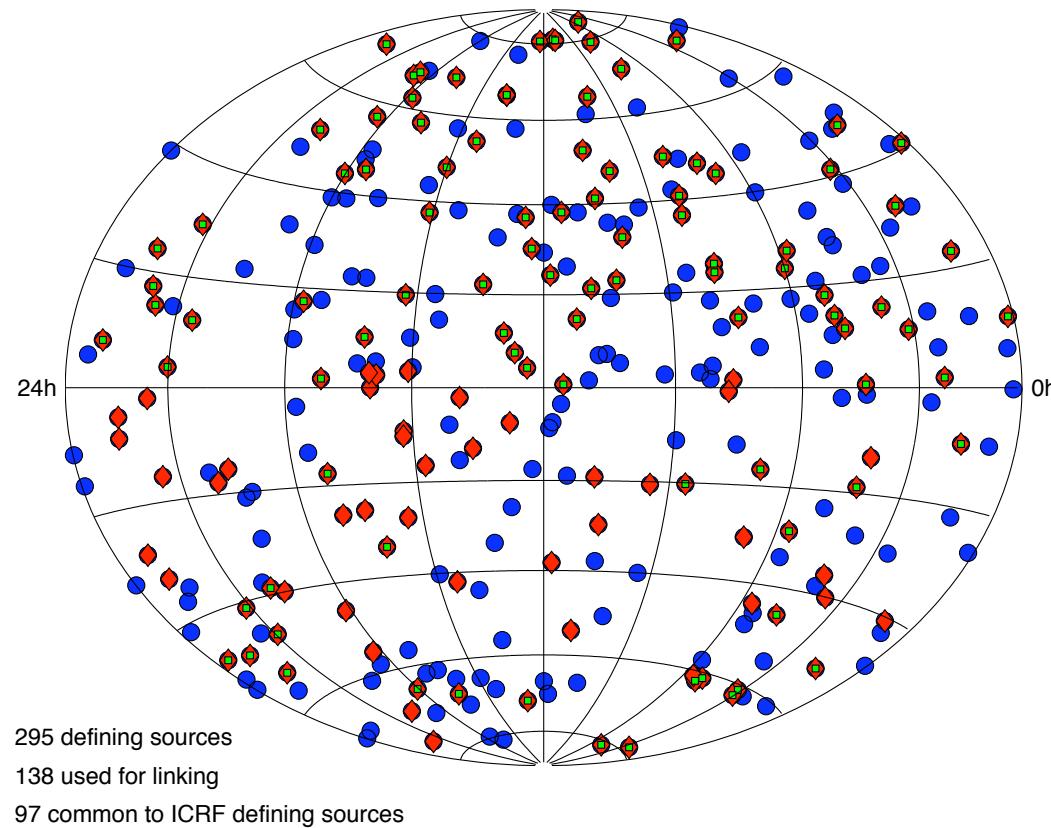


Fig. 40.— Distribution of the 295 defining sources (blue circles), of the 138 used for linking ICRF2 to ICRF-Ext.2 (red diamonds). The 97 ICRF2 defining sources that are also defining sources of the ICRF1 are marked with green squares.



“Defining” sources

- “295 new defining sources selected on the basis of positional stability and the lack of extensive intrinsic source structure. The stability of these 295 defining sources, and their more uniform sky distribution eliminates the two largest weaknesses of ICRF1.”

Draft technical note – July 2009.

- ICRF2 defining sources:

| | | | | | | | | | | | |
|-----------------------|----------|-------------------|-------------------|------------|-----------|--------|---------|---------|---------|----|-----|
| ICRF J235935.4-313343 | 2357-318 | 23 59 35.49154293 | -31 33 43.8242510 | 0.00000861 | 0.0002660 | 0.051 | 53392.9 | 52409.7 | 54872.7 | 9 | 257 |
| ICRF J223912.0-570100 | 2236-572 | 22 39 12.07592367 | -57 01 00.8393966 | 0.00001773 | 0.0002127 | 0.312 | 53973.7 | 53223.4 | 54670.7 | 10 | 54 |
| ICRF J182912.4-581355 | 1824-582 | 18 29 12.40237320 | -58 13 55.1616899 | 0.00002140 | 0.0002150 | 0.403 | 54023.5 | 53223.4 | 54726.7 | 10 | 58 |
| ICRF J055009.5-573224 | 0549-575 | 05 50 09.58018296 | -57 32 24.3965304 | 0.00001696 | 0.0002398 | 0.372 | 53796.1 | 53223.4 | 54670.7 | 10 | 64 |
| ICRF J182332.8+685752 | 1823+689 | 18 23 32.85390304 | 68 57 52.6125919 | 0.00001275 | 0.0000816 | 0.009 | 53891.4 | 49827.5 | 54901.7 | 10 | 419 |
| ICRF J113624.5-033029 | 1133-032 | 11 36 24.57693290 | -03 30 29.4964694 | 0.00000509 | 0.0001256 | -0.038 | 53907.2 | 50576.2 | 54845.7 | 10 | 474 |
| ICRF J101810.9+354239 | 1015+359 | 10 18 10.98809086 | 35 42 39.4408279 | 0.00000525 | 0.0001043 | 0.024 | 53327.1 | 50242.8 | 54880.7 | 10 | 493 |
| ICRF J184822.0+321902 | 1846+322 | 18 48 22.08858135 | 32 19 02.6037429 | 0.00000451 | 0.0000830 | -0.018 | 53653.9 | 50219.8 | 54865.7 | 10 | 573 |
| ICRF J080518.1+614423 | 0800+618 | 08 05 18.17956846 | 61 44 23.7002968 | 0.00000740 | 0.0000609 | -0.147 | 54532.8 | 52409.7 | 54887.7 | 10 | 981 |
| ICRF J052616.6-483036 | 0524-485 | 05 26 16.67131064 | -48 30 36.7915470 | 0.00001592 | 0.0002543 | 0.400 | 53913.6 | 53223.4 | 54726.7 | 11 | 68 |



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MFV analysis method (1)

- Publications in A&A :
 - 2001: “Stability of the extragalactic VLBI reference frame” – A.-M. Gontier, K. Le Bail, M. Feissel, T. M. Eubanks;
 - 2003: “Selecting stable extragalactic compact radio sources from the permanent astrogeodetic VLBI program” – M. Feissel-Vernier;
 - 2006: “Analysis strategy issues for the maintenance of the ICRF axes” – M. Feissel-Vernier, C. Ma, A.-M. Gontier, C. Barache.



MFV analysis method (2)

- Source coordinates derived by Fey (2002) over 1979-2002;
- First selection: criteria based on continuity
 - Period from 1989.5-2002.4;
 - Length of observation period longer than 5 years;
 - Not less than two observations of the source in a given session;
 - One-year average coordinates based on at least three observations;
 - Not more than three successive years with no observations;
 - At least half of the one-year averages available over the source observation span.
- Network of 362 sources.



MFV analysis method (3)

- Analyze of time series of yearly values of $\alpha \cos\delta$ and δ :
 - The linear drift;
 - The normalized drift;
 - The standard deviation;
 - The Allan standard deviation for a one-year sampling time.
- Study of five quantities:
 - (1) Standard deviation only;
 - (2) Allan standard deviation only;
 - (3) Normalized velocity only;
 - (4) Standard deviation and normalized velocity;
 - (5) Allan standard deviation and normalized velocity.



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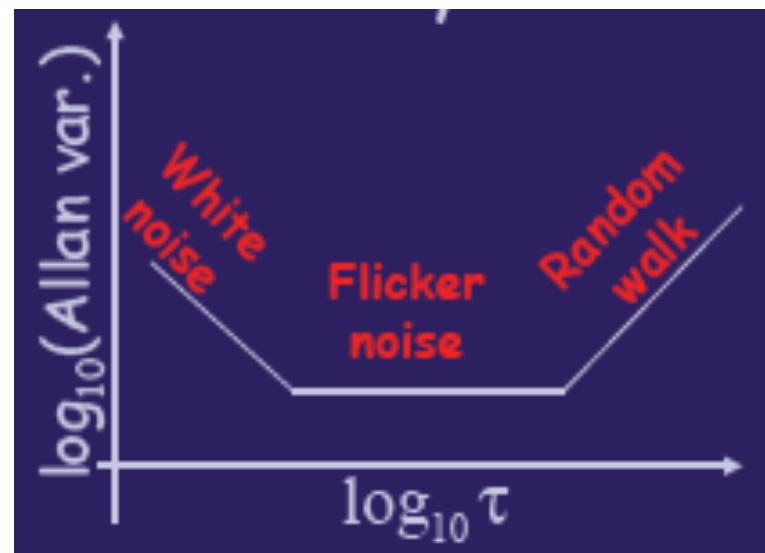


MFV analysis method (4)

Allan Variance

- If (x_i) are the measurements and T the sampling time:

$$\sigma^2(T) = \frac{1}{2} < (\bar{x}_{i+1} - \bar{x}_i)^2 >$$





MFV analysis method (5)

- Stability criteria: based on the combination of Allan standard deviations and normalized drifts for $(\alpha \cos \delta, \delta)$;
- The value of the stability index for a source: (1,2,3,4).

| Statistics | Threshold | Partial index |
|--------------------------|---|---------------|
| Allan Standard Deviation | $\leq 100 \mu\text{as}$ | 1 |
| | $100 \mu\text{as} \leq \dots \leq 200 \mu\text{as}$ | 2 |
| | $200 \mu\text{as} \leq \dots \leq 300 \mu\text{as}$ | 3 |
| | $\geq 300 \mu\text{as}$ | 10 |
| Normalized Drift | ≤ 1 | 1 |
| | $1 \leq \dots \leq 3$ | 2 |
| | ≥ 3 | 3 |



MFV analysis method (6)

- Same study applied to aug24;
- 229 sources passed the first test of selection (362);
- 68% of agreement:
 - 92 stable sources;
 - 63 unstable sources.
- 32% of disagreement:
 - 22 sources considered stable for MFV and unstable for KLB;
 - 52 sources considered stable for KLB and unstable for MFV.

| Sources number | 1 KLB | 2 KLB | 3 KLB | 4 KLB | Total MFV |
|----------------|------------|-----------|-----------|-----------|------------|
| 1 MFV | 17 | 4 | 2 | 17 | 40 |
| 2 MFV | 67 | 4 | 8 | 25 | 104 |
| 3 MFV | 4 | 1 | 1 | 0 | 6 |
| 4 MFV | 16 | 1 | 8 | 54 | 79 |
| Total KLB | 104 | 10 | 19 | 96 | 229 |



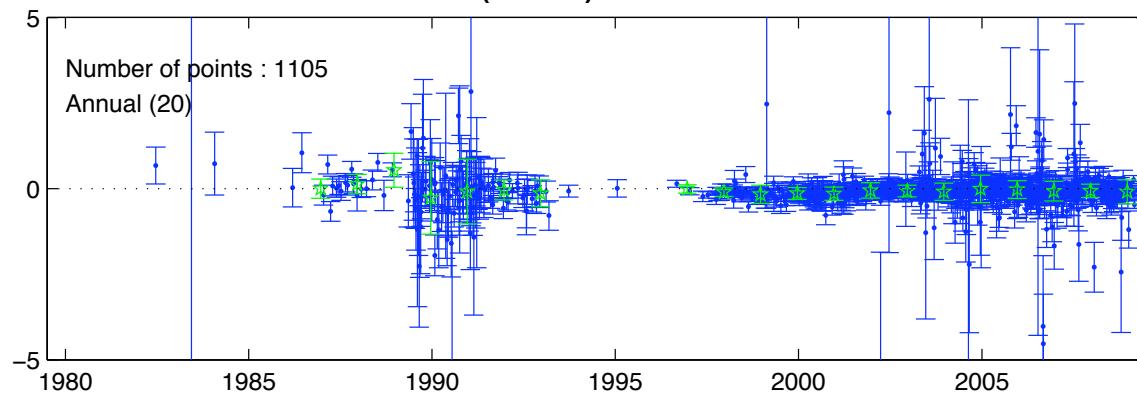
Drawbacks of this method

- Stationary noise – BUT: Has a source the same behavior with time? No: strategy analysis, geometry of the observations, change in the instruments,...
- One-year average – Already smoothing time series. What is hidden behind that? Can we decrease the sampling time to obtain more points in the Allan variance plot to obtain a more precise determination of the slope?

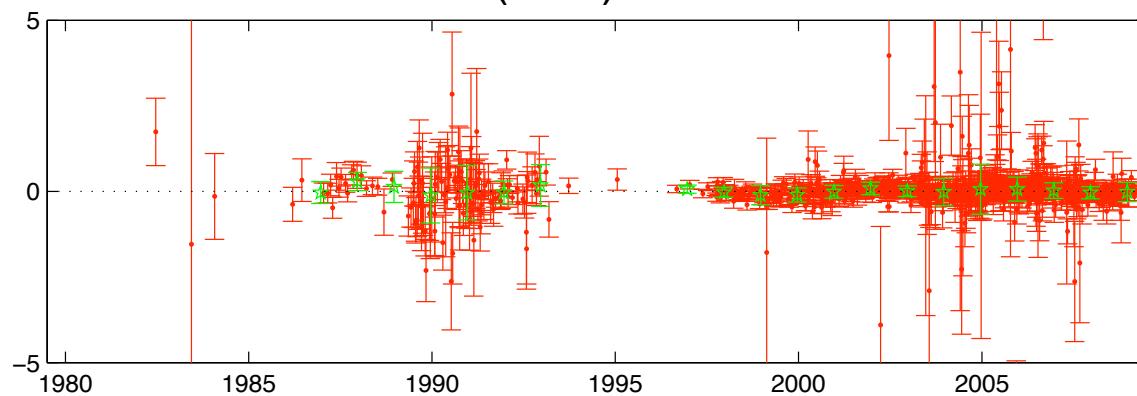


Stationary assumption

RA (mas) – 3C418



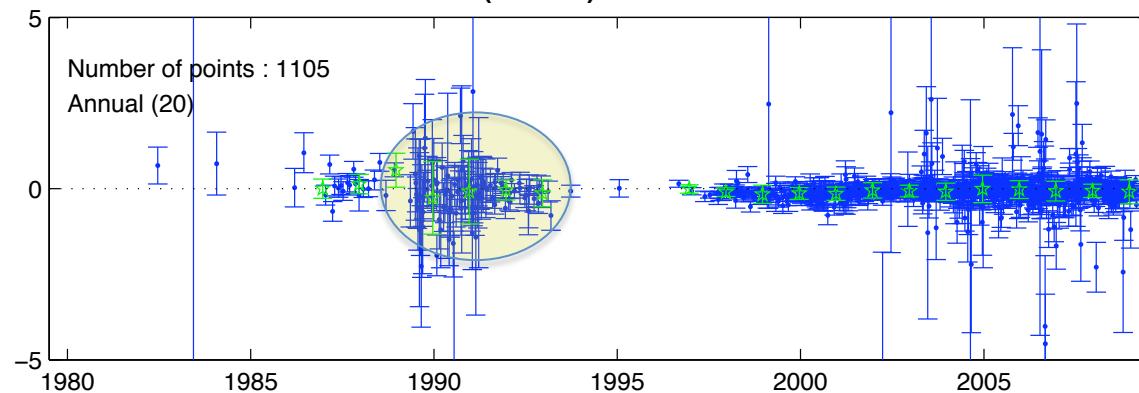
DEC (mas) – 3C418



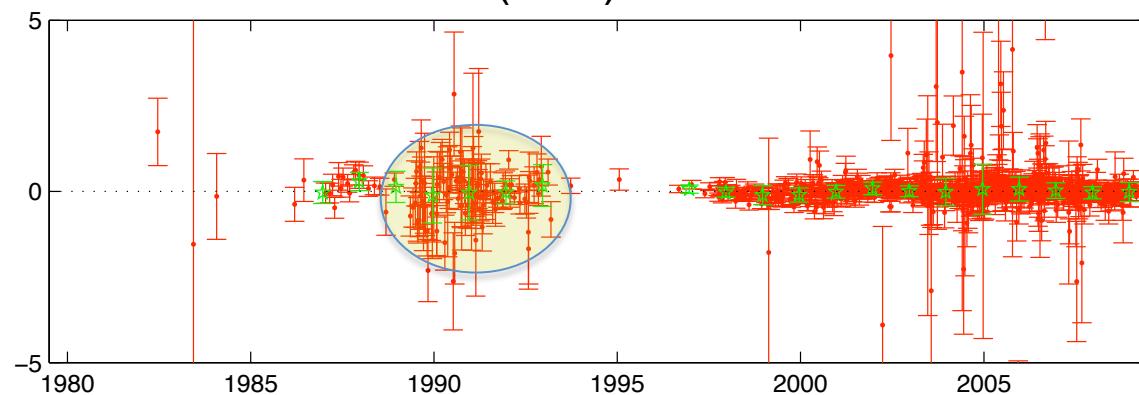


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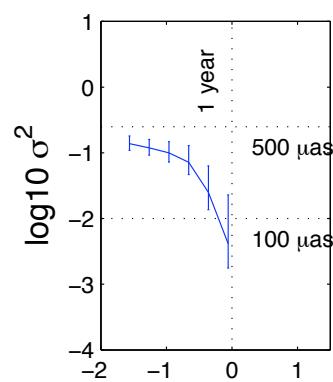
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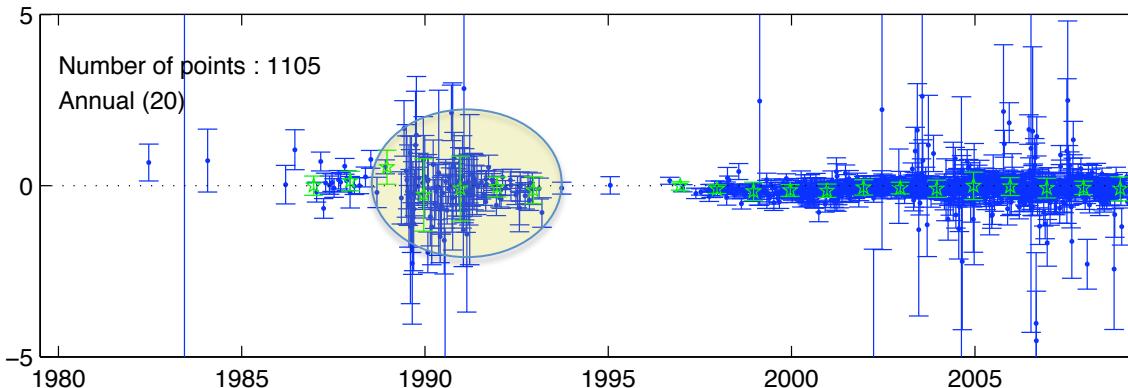


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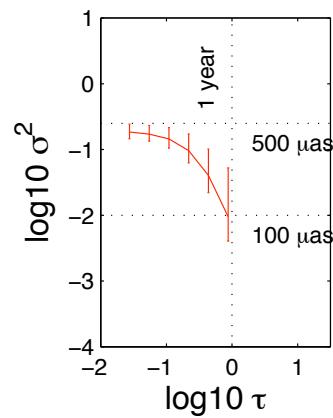
Allan variance



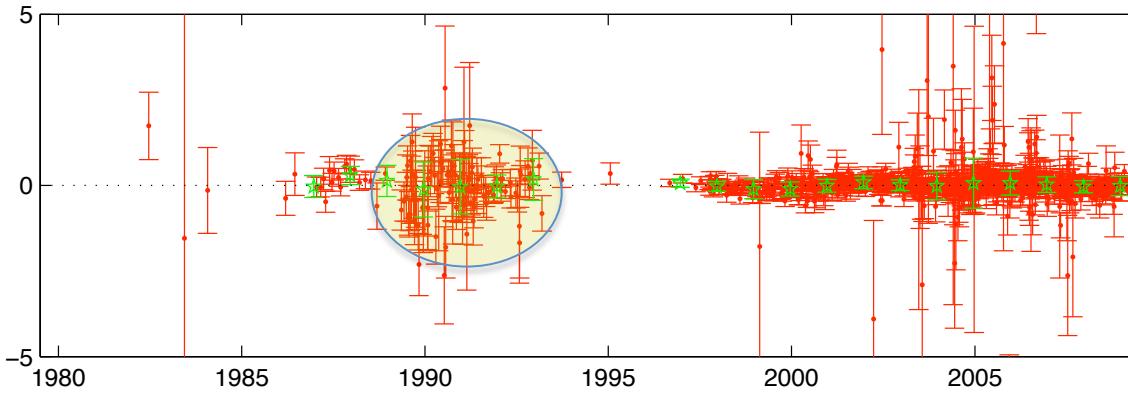
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Allan variance

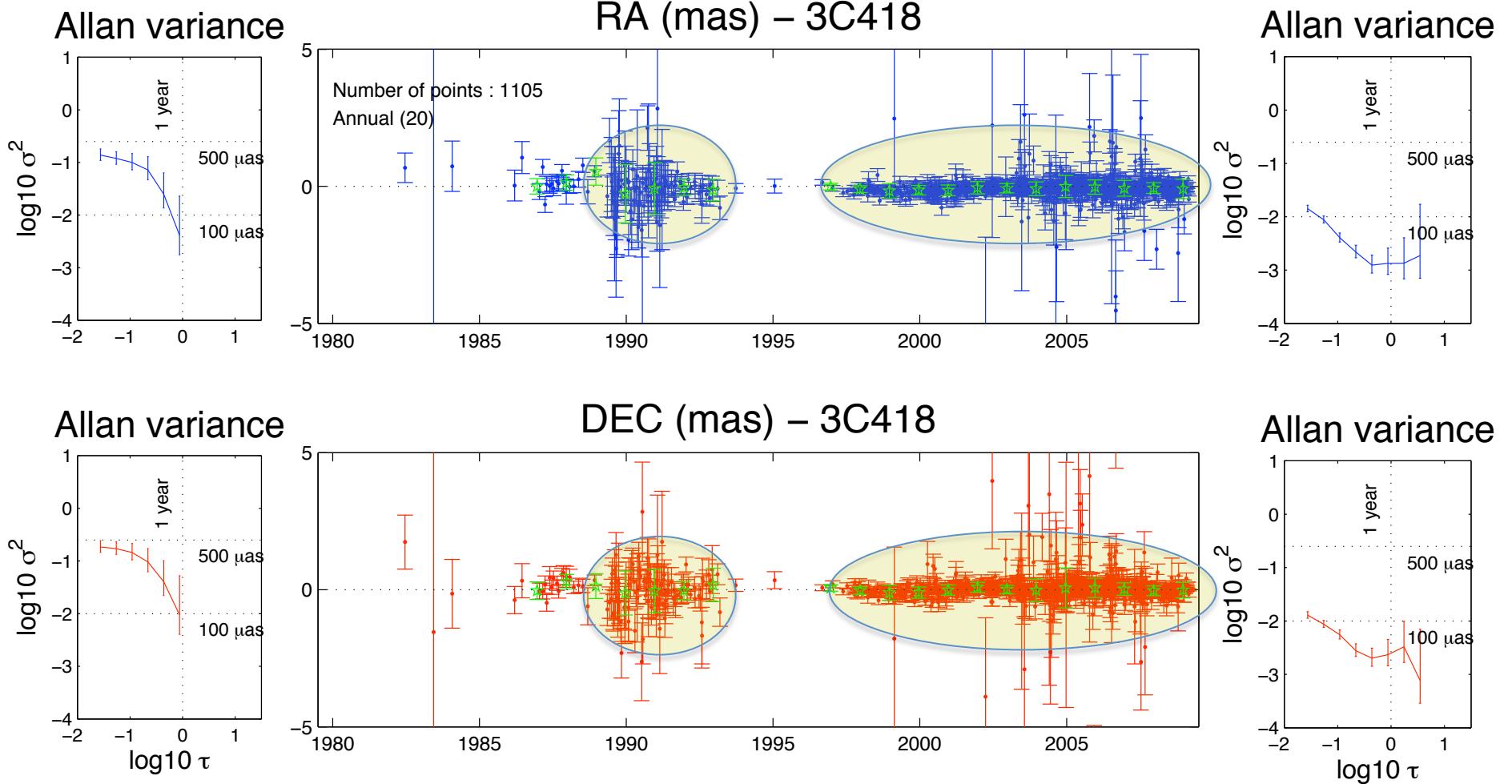


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Stationary assumption





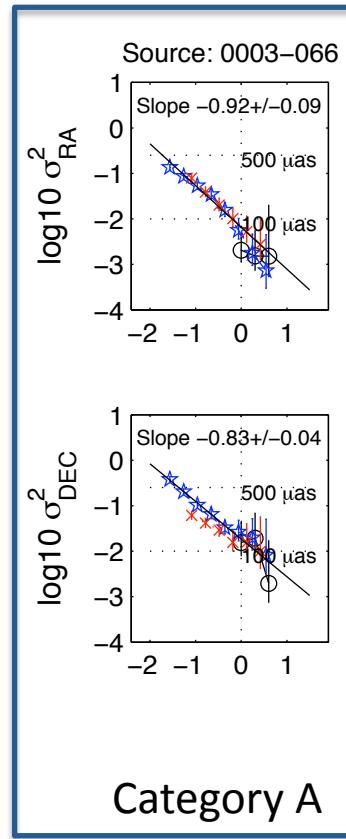
KLB analysis method (1)

- From gsf005a, the preprocessing consists on:
 - Eliminate 930 sources with less than 30 points and 112 more because the observations are too scattered within the time span;
 - Delete the outliers at 3-sigma;
 - Divide time series (162 sources left):
 - 2 sources unmodified;
 - 1 divided in 3 time series;
 - 22 in 2 time series;
 - 137 sources cleaned.
 - Compute average time series of one-year, 30-day and 10-day.
- 186 time series.



KLB analysis method (2)

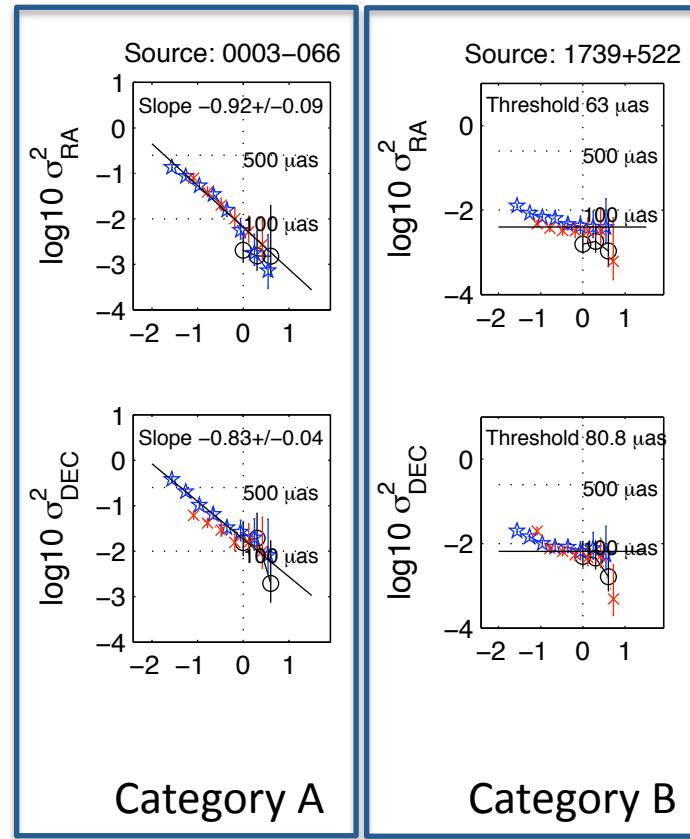
- Three categories depending on the type of noise:
 - **Category A:** White noise (115);
 - Category B: Flicker noise or threshold (45);
 - Category C: Apparent motion (26).





KLB analysis method (2)

- Three categories depending on the type of noise:
 - Category A: White noise (115);
 - **Category B:** Flicker noise or threshold (45);
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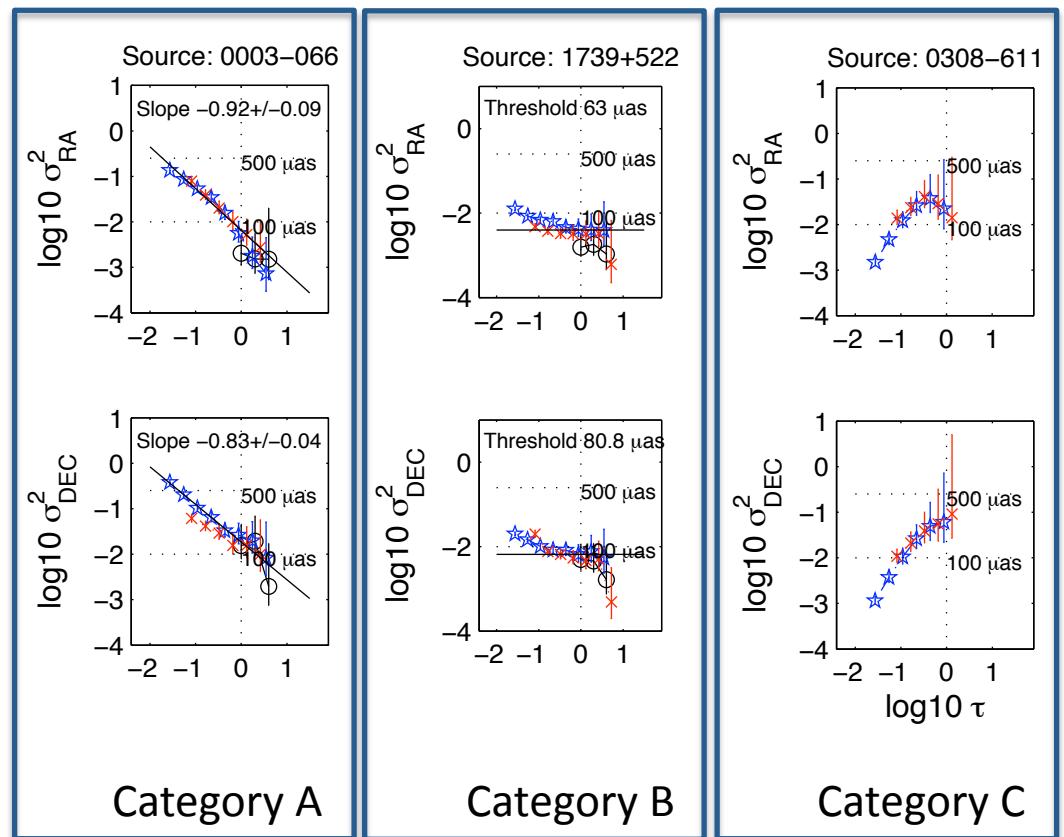
Category A

Category B



KLB analysis method (2)

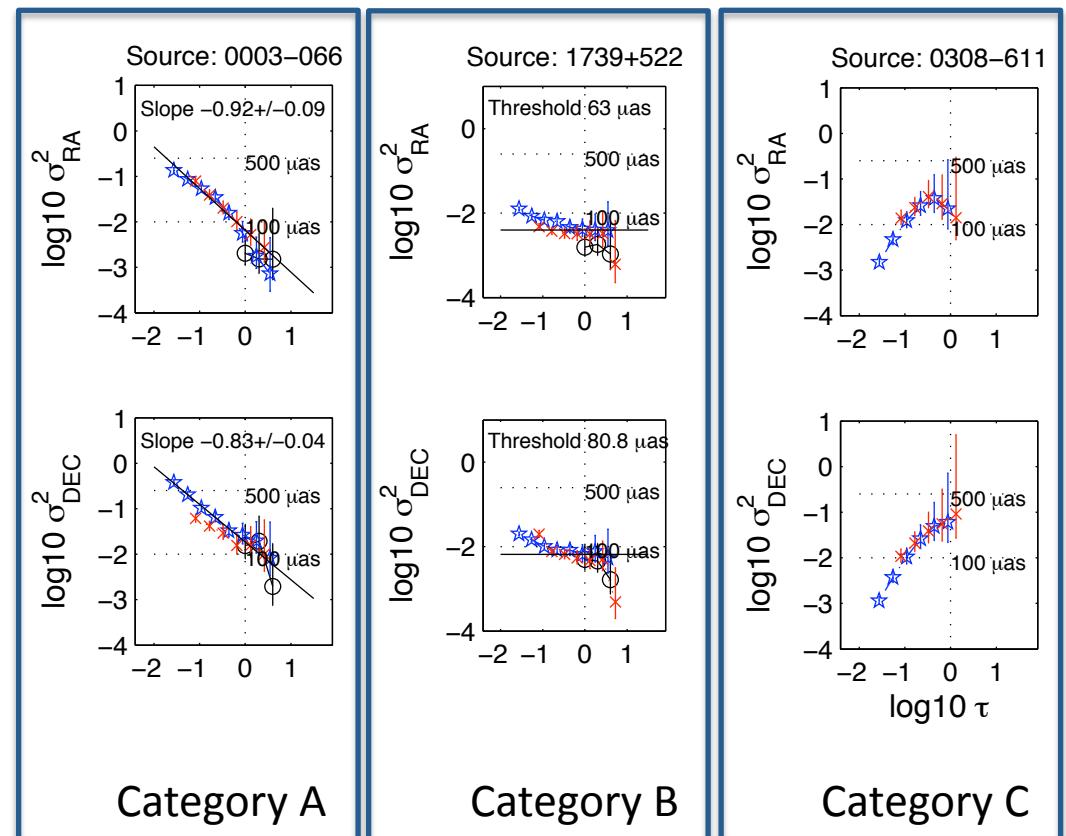
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KLB analysis method (2)

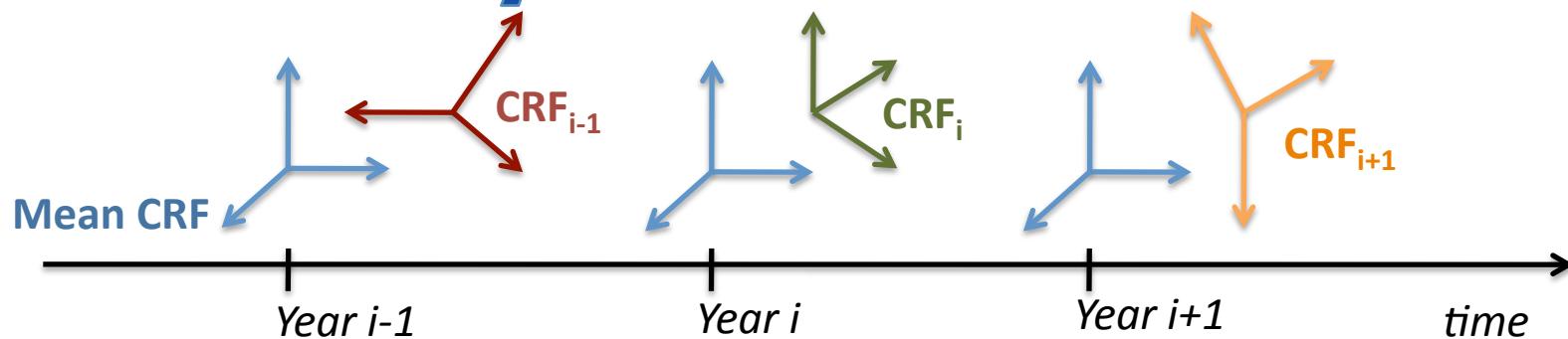
- Category A:
The quality of the data
is improving with time;
- Category B:
The quality of the data
is stabilized at a certain
level of noise;
- Category C:
This is impossible to
have a clear conclusion
due to some "signal" in
the time series.





How do we know the selection realizes a stable ICRF?

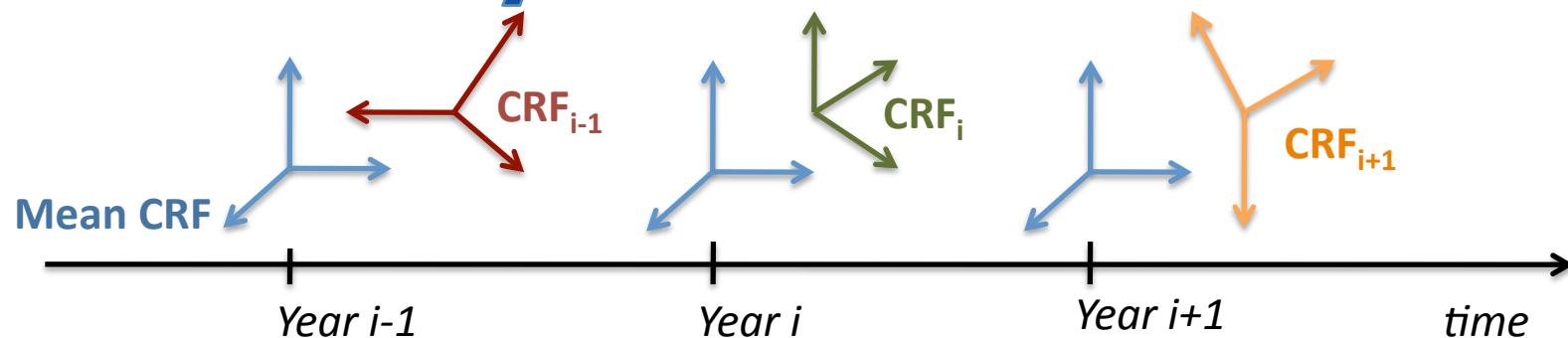
Stability test on a mean CRF



$$\begin{cases} (\alpha_m - \alpha_i) \cos \delta_m &= A_1(i) \tan \delta_i \cos \alpha_i + A_2(i) \tan \delta_i \sin \alpha_i - A_3(i) \\ \delta_m - \delta_i &= -A_1(i) \sin \alpha_i + A_2(i) \cos \alpha_i + dz(i) \end{cases}$$

- Test applied to the following selections of sources:
 - Defining sources;
 - Selection of MFV (2003);
 - Selection of KLB using MFV criteria;
 - Selection of KLB.

Stability test on a mean CRF



$$\begin{cases} (\alpha_m - \alpha_i) \cos \delta_m &= A_1(i) \tan \delta_i \cos \alpha_i + A_2(i) \tan \delta_i \sin \alpha_i - A_3(i) \\ \delta_m - \delta_i &= -A_1(i) \sin \alpha_i + A_2(i) \cos \alpha_i + dz(i) \end{cases}$$

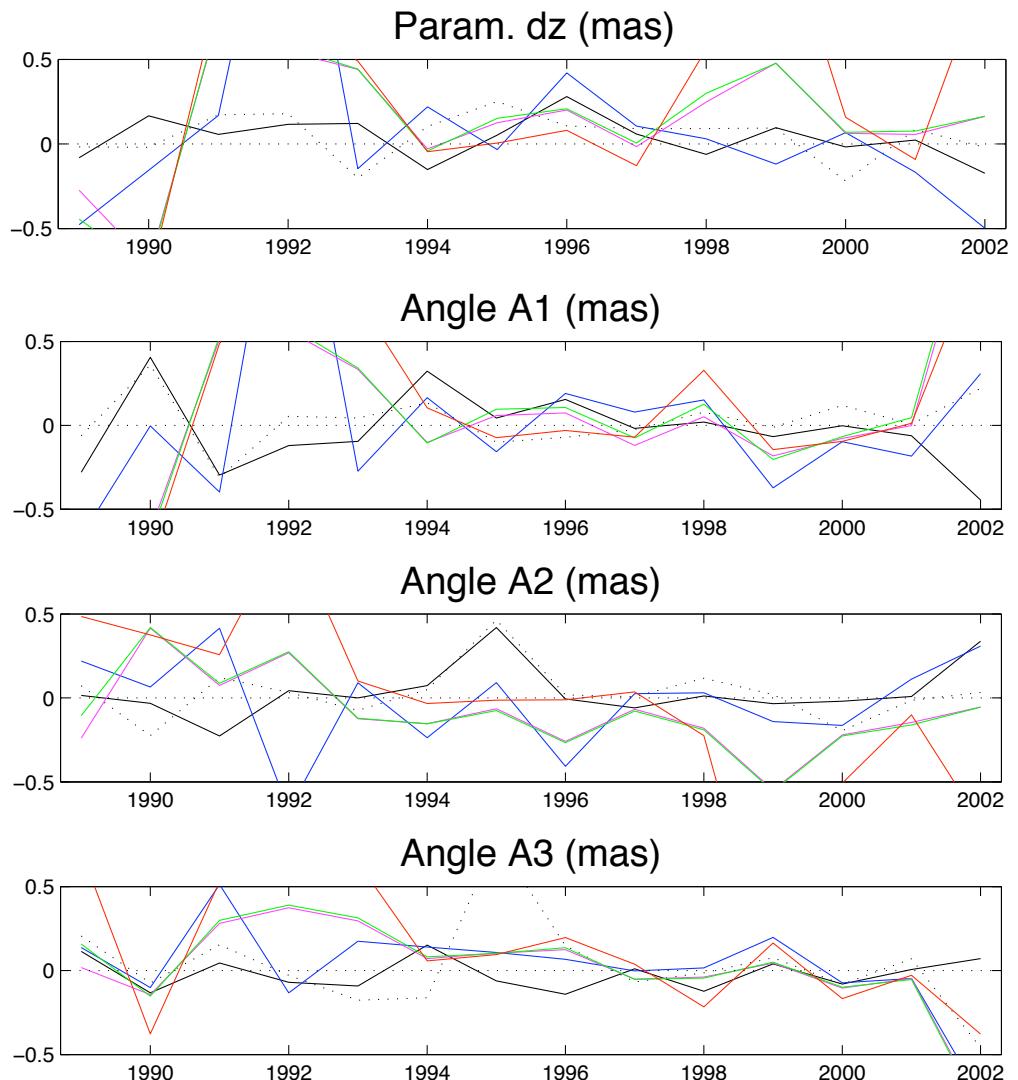
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Defining sources and MFV selection with MFV criteria

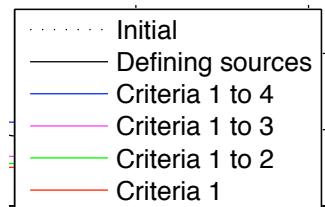
Initial
Defining sources
Criteria 1 to 4
Criteria 1 to 3
Criteria 1 to 2
Criteria 1

| Median and std (mas) | Sources number | A1 | A2 | A3 | dz |
|----------------------------|-------------------|------------------------|------------------------|------------------------|-------------------------|
| Initial | 410 | 0.025 +/- 0.158 | 0.026 +/- 0.161 | -0.021 +/- 0.275 | 0.091 +/- 0.134 |
| Defining sources | 176 | -0.038 +/- 0.227 | 0.006 +/- 0.158 | -0.027 +/- 0.095 | 0.056 +/- 0.123 |
| Criteria 1 to 4 | 82 | -0.051 +/- 0.607 | 0.047 +/- 0.286 | 0.041 +/- 0.275 | -0.00 2 +/- 0.624 |
| Criteria 1 to 3 | 47 | 0.024 +/- 0.552 | -0.135 +/- 0.234 | 0.031 +/- 0.286 | 0.144 +/- 0.360 |
| Criteria 1 to 2 | 44 | 0.071 +/- 0.573 | -0.113 +/- 0.234 | 0.066 +/- 0.298 | 0.158 +/- 0.387 |
| Criteria 1 | 18 | -0.010 +/- 1.207 | -0.013 +/- 0.635 | 0.076 +/- 0.402 | 0.119 +/- 1.141 |

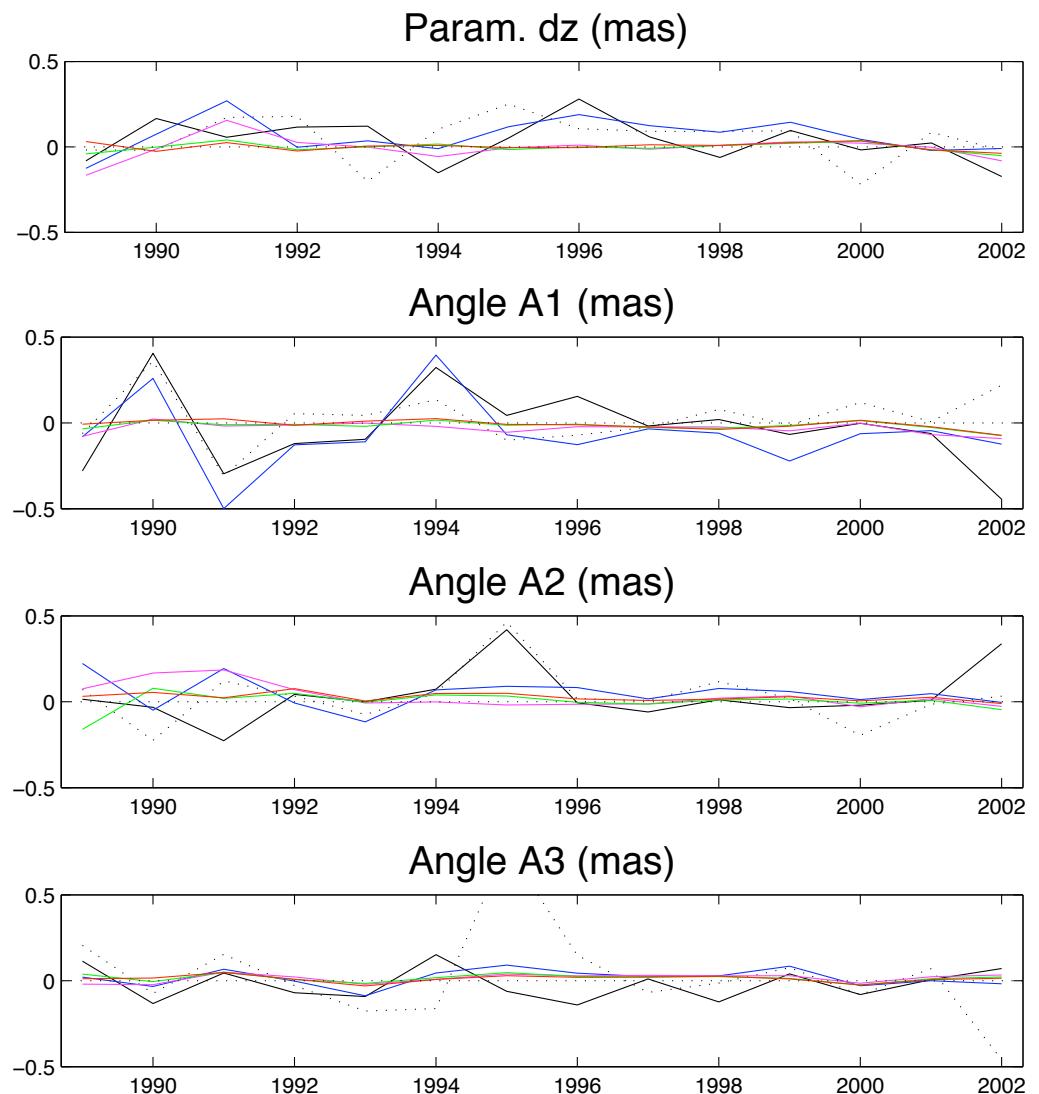




Defining sources and KLB selection with MFV criteria



| Median and std (mas) | Sources number | A1 | A2 | A3 | dz |
|----------------------------|-------------------|------------------------|-----------------------|------------------------|-------------------------|
| Initial | 410 | 0.025 +/- 0.158 | 0.026 +/- 0.161 | -0.021 +/- 0.275 | 0.091 +/- 0.134 |
| Defining sources | 176 | -0.038 +/- 0.227 | 0.006 +/- 0.158 | -0.027 +/- 0.095 | 0.056 +/- 0.123 |
| Criteria 1 to 4 | 215 | -0.075 +/- 0.205 | 0.053 +/- 0.089 | 0.023 +/- 0.049 | 0.059 +/- 0.100 |
| Criteria 1 to 3 | 124 | -0.023 +/- 0.032 | 0.009 +/- 0.069 | 0.026 +/- 0.025 | -0.00 2 +/- 0.070 |
| Criteria 1 to 2 | 106 | -0.015 +/- 0.024 | 0.009 +/- 0.056 | 0.020 +/- 0.022 | -0.00 1 +/- 0.026 |
| Criteria 1 | 97 | -0.010 +/- 0.026 | 0.024 +/- 0.024 | 0.013 +/- 0.020 | 0.007 +/- 0.023 |

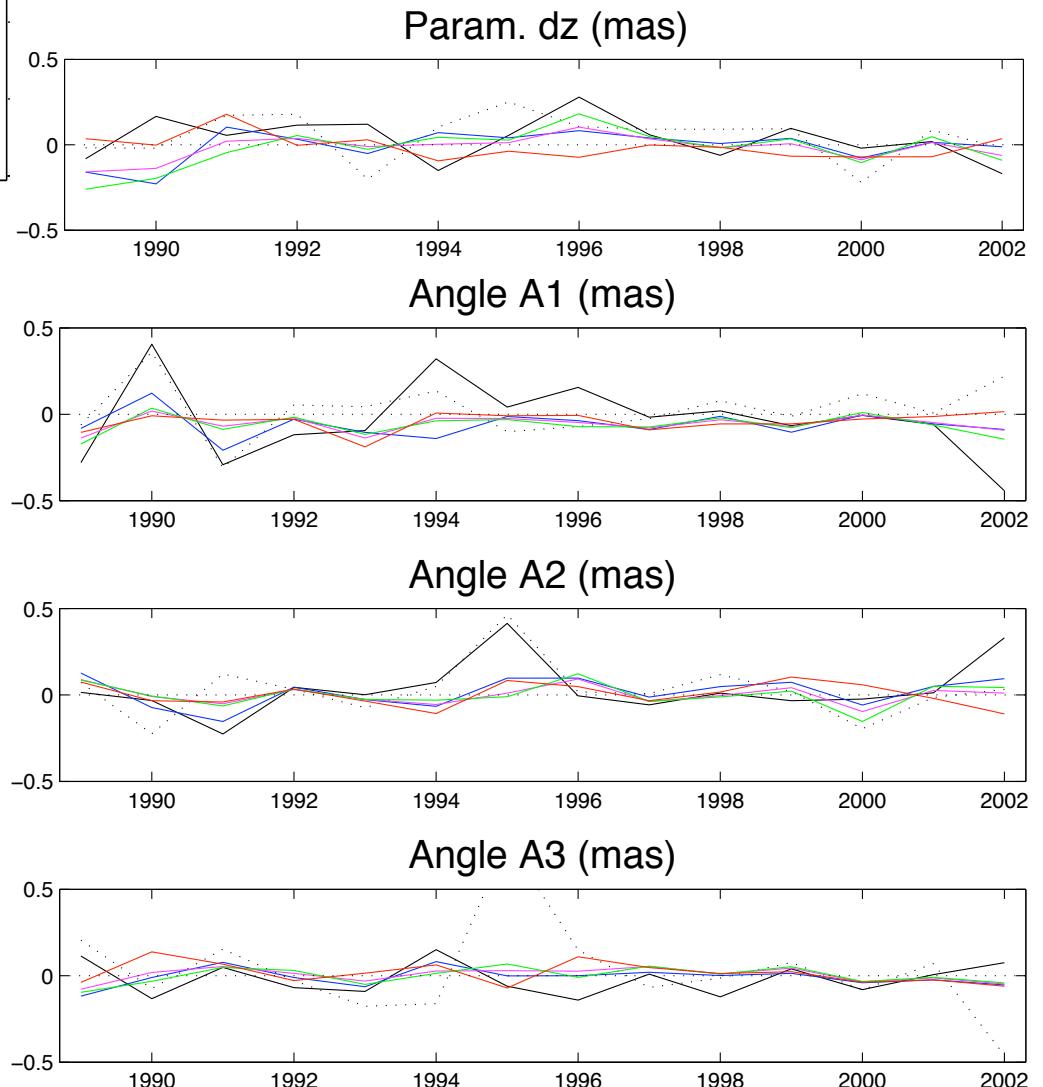




**KLB selection with
KLB criteria
No level of noise
taken into account**

Initial
Defining sources
Criteria A/B/C
Criteria A/B
Criteria A
Criteria B

| Median and std (mas) | Sources number | A1 | A2 | A3 | dz |
|----------------------------|-------------------|------------------------|------------------------|------------------------|-----------------------|
| Initial | 410 | 0.025 +/- 0.158 | 0.026 +/- 0.161 | -0.021 +/- 0.275 | 0.091 +/- 0.134 |
| Defining sources | 176 | -0.038 +/- 0.227 | 0.006 +/- 0.158 | -0.027 +/- 0.095 | 0.056 +/- 0.123 |
| Categ. A/B/C | 147 | -0.069 +/- 0.077 | 0.047 +/- 0.083 | -0.005 +/- 0.522 | 0.024 +/- 0.094 |
| Categ. A/B | 128 | -0.048 +/- 0.046 | 0.003 +/- 0.053 | 0.016 +/- 0.040 | 0.005 +/- 0.070 |
| Categ. A | 91 | -0.067 +/- 0.057 | -0.008 +/- 0.067 | 0.000 +/- 0.048 | 0.005 +/- 0.113 |
| Categ. B | 36 | -0.029 +/- 0.054 | -0.002 +/- 0.068 | 0.013 +/- 0.063 | -0.00 +/- 0.070 |

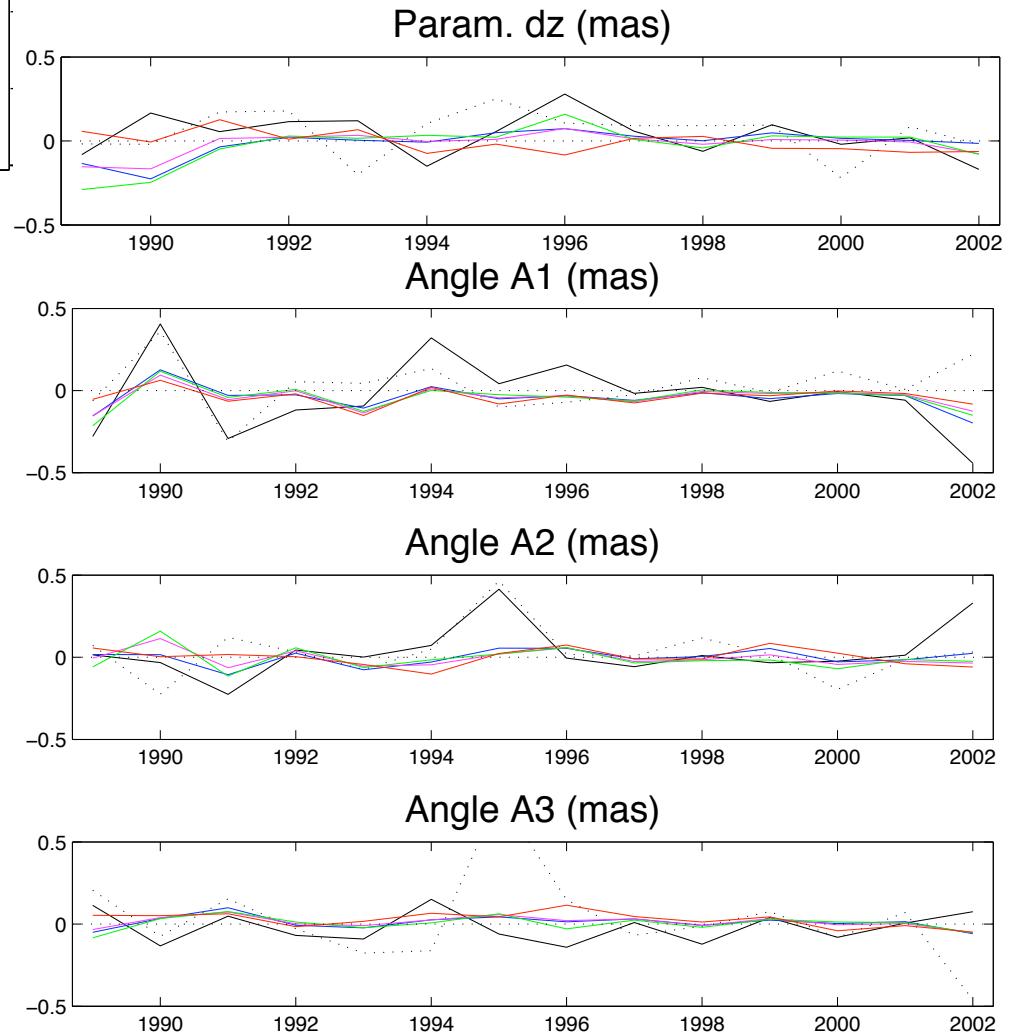




KLB selection with KLB criteria Level of noise taken into account

Initial
Defining sources
Criteria A/B/C
Criteria A/B
Criteria A
Criteria B

| Median and std (mas) | Sources number | A1 | A2 | A3 | dz |
|----------------------------|-------------------|------------------------|------------------------|------------------------|-----------------------|
| Initial | 410 | 0.025 +/- 0.158 | 0.026 +/- 0.161 | -0.021 +/- 0.275 | 0.091 +/- 0.134 |
| Defining sources | 176 | -0.038 +/- 0.227 | 0.006 +/- 0.158 | -0.027 +/- 0.095 | 0.056 +/- 0.123 |
| Categ. A/B/C | 116 | -0.031 +/- 0.076 | 0.010 +/- 0.048 | 0.014 +/- 0.040 | 0.004 +/- 0.078 |
| Categ. A/B | 104 | -0.028 +/- 0.065 | -0.020 +/- 0.050 | 0.012 +/- 0.034 | 0.007 +/- 0.068 |
| Categ. A | 69 | -0.027 +/- 0.080 | -0.019 +/- 0.068 | 0.011 +/- 0.043 | 0.019 +/- 0.116 |
| Categ. B | 33 | -0.029 +/- 0.052 | 0.003 +/- 0.052 | 0.044 +/- 0.045 | 0.013 +/- 0.062 |

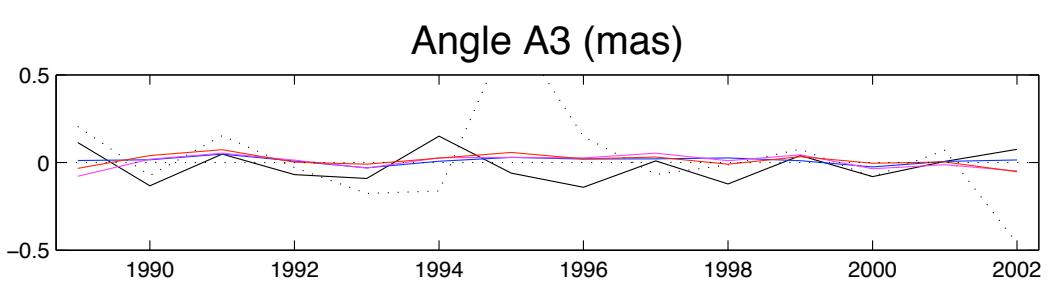
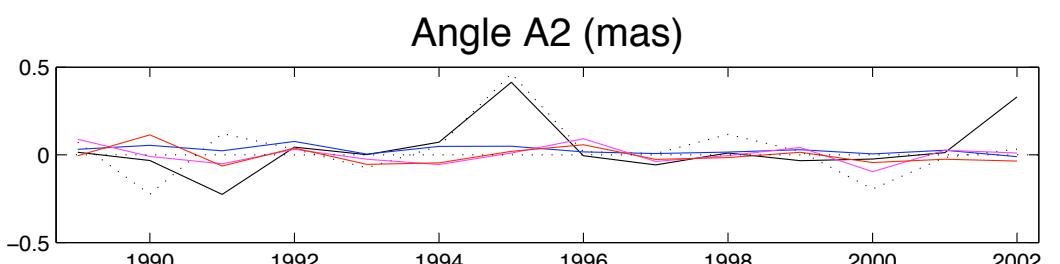
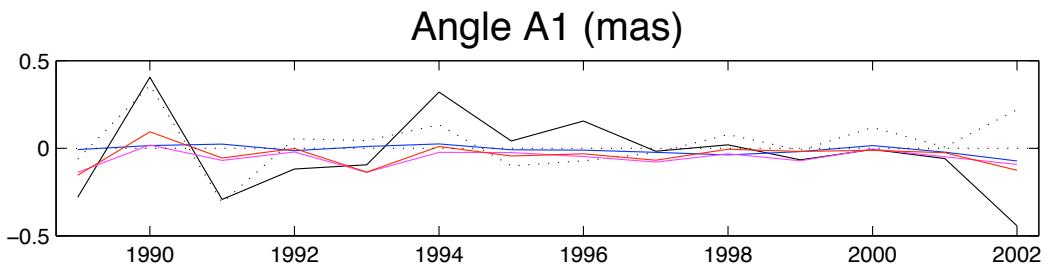
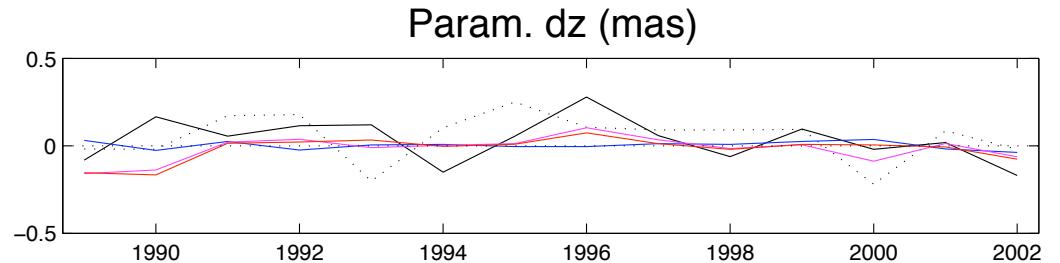




Comparison

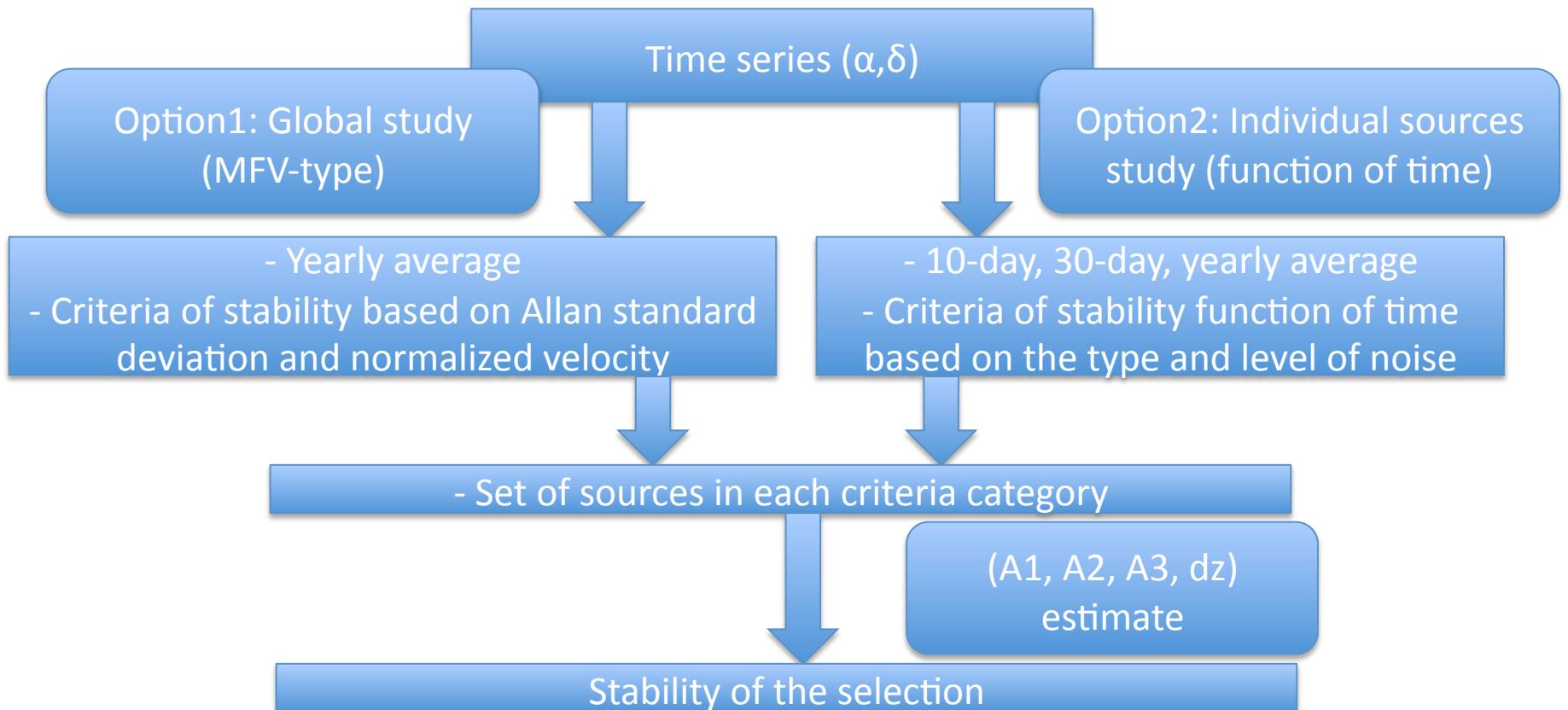
- Conclusions
 - Defining sources are the selection giving the less stable CRF;
 - The 3 KLB selections show comparable results in A3;
 - In A1, A2 and dz, the three curves show the same stability from 1995 to the end.
- Work in progress
 - KLB criteria as a function of time;
 - Extending the period to 2009;
 - Those tests will answer the following question: is the stability of the CRF dependent on the network, then on the homogeneous cover of the sky?

Initial
Defining sources
KLB/MFV selection
KLB/type
KLB/type and level





A new tool to study the stability of time series of VLBI sources



- Comparison with other VLBI analysis centers.



Conclusions

- An update of the selection of good sources shows a better stability than the selection of MFV (2003);
- The selection of stable sources is dependent on the set of time series studied;
- Comparison with other Analysis Centers.